



# Detecting High Impedance Ground Faults

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## CIRCUIT PROTECTION

### Detecting high impedance ground faults

“A case of establishing probabilities, of pattern recognition using artificial intelligence.”

By Denise Deveau

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*Oscillographic capture, triggered by internal signals or an external contact, of current waveform (at 32 samples per cycle) by Digital Feeder Protection device.*

For many years, utilities have been addressing the challenge of detecting high impedance (Hi-Z) ground faults. Depending on the conductivity of the surface where the fault occurs, conventional detection technologies, which are based on a measurement of current magnitude, may not function. It is these dangerous high-impedance, down-conductor faults that are the focus of concern for many protection engineers.

Surfaces such as grass, clay, concrete or foliage act as an insulator, limiting the line current values for the faults on a distribution system to a low range of magnitude -- typically less than 50 amps. Under these conditions, normal protection relays are unable to distinguish between the high-impedance faults and common load imbalances. Carl Benner, Research Engineer at Texas A&M University in College Station, Texas, explains that the university has been researching Hi-Z test procedures for 20 years and has staged hundreds of tests. "Contrary to popular belief, conventional protection is unable to deal with downed conductors effectively. There are no good statistics on how often conventional protection fails to de-energize downed lines, but linemen who

respond to trouble calls report that up to one-third to one-half of downed conductors are still hot when they arrive on the scene. We've staged hundreds of faults at numerous utilities and at our own dedicated test facility, and our results bear this out. More than half the time, we fail to blow even relatively small fuses when we put a Hi-Z fault on a feeder with several thousand amps of available fault current."

#### **The high cost of failure**

Because the fault is not detected (due to the low magnitudes of the fault currents), the high system voltage continues to exist on the broken cable. The arcing that results under these conditions can have deadly consequences. "When a conductor falls to the ground, the resulting arc can reach temperatures up to 3000°F. This can crystallize the silica in the surrounding ground, eventually creating a path to ground and a situation in which there is no visible sign that the conductor is energized," explains Mark Adamiak, Manager of Utility Integration Systems with Malvern, PA-based GE Power Management, manufacturers of protection, metering and control equipment for large generating plants and substations for industrial operations.

The inability to detect Hi-Z faults poses considerable safety risks -- to humans, animals and to natural environments. This is especially true in remote areas, where the best line of defense to date has been a timely phone call from an observant passer-by who sees the line on the ground, or a resident experiencing a power outage. Even in urban areas, however, arcing in underground cables can -- and has -- led to explosions when it happens in the vicinity of gas lines. In addition to the ethical reasons to reduce the safety risks, utilities also face the resulting legal liability risks.

### **Digital feeder protection (DFP) technology**

The Texas research team's response to this challenge was to develop a means of detection based on digital feeder protection technology. "Prototype installations at several utilities had validated our approach of enhancing detection sensitivity by looking at current components other than the dominant fundamental frequency," says Benner. Angelo D'Aversa, Product Engineer with GE Power Management, the University's business partner in bringing the technology to market, confirms that successful Hi-Z testing is in large part a function of capturing and analyzing harmonics by the relay: "Although harmonics are always present in power systems, detecting arcing on a feeder is a question of monitoring the randomness and energy fluctuations of the harmonics over a set period of time. By tracking these measurements, one can determine, with a relatively high level of confidence, the presence of a Hi-Z fault and set the DFP 200 to issue an output when those levels are reached."

"Most relays measure fundamental frequencies only (50/60 Hz)," he

explains, "The overall Hi-Z algorithm considers frequencies from the sub-harmonic to the 13th harmonic, not including the fundamental frequency. What you are looking for in simple terms, is certain patterns that indicate arcing and these patterns are found in the harmonics of the system. This pattern recognition, through the use of artificial intelligence, allows us to distinguish arcing from a downed-conductor from loads that generate large amounts of harmonics. Conventional overcurrent protection is extremely predictable in its operating times for a given fault current. However, because the Hi-Z algorithm is looking for certain events to occur in the harmonic content of the current, it isn't as predictable in its operating times." Because it involves monitoring and tracking of odd and even harmonics, as well as non-harmonics over time (i.e. 45 seconds to minutes), he adds that "the correct use of the Hi-Z algorithm comes with experience with the product." The sensitivity settings on the relay take into account a number of factors, including the simultaneous combination of 24 routines looking at the energy levels and randomness for the odd and even harmonics and non-harmonics. The relay then uses these routines, as well as other logic, as an input to an Expert Arc Detector to detect Hi-Z faults. Through the DFP 200's use of expanded RMS oscillography captures, the end-user can get a picture of the arcing current, as well as follow the logic inside the Hi-Z algorithm as the fault occurred.

### **Field tests and commercial development**

By the early 1990s, long-term field prototype installations had demonstrated the ability of DFP devices to detect a

majority of Hi-Z faults, and the university was ready to move forward to the commercial development phase. Says Benner, "At this point, we sought a business partner that could bring the technology to market. We worked closely with GE and a number of utility advisors to develop requirements for a practical device. One of the most important of these was that it not be prone to 'false alarms,' -- a serious concern to utilities contemplating application of the technology in the real world."

The university decided to partner with GE Power Management in developing digital feeder protection (DFP) technology for Hi-Z monitoring and detection. Since commercial development began, GE Power Management has worked with utilities around the world to test the technology, including utilities in Spain, the United States, Venezuela and Canada. The university's research team has continued to support GE in these efforts.

Bill Tyska of GE Power Management observes, "GE Power Management has encouraged and supported Hi-Z detection testing by electric utilities in an effort to confirm and improve the viability of Hi-Z detection algorithms developed by Dr. B. Don Russell, Carl Benner and associates at Texas A&M University. Early efforts to confirm that the Texas A&M Hi-Z detection algorithms were correctly incorporated into GE's Hi-Z detection package involved the cooperation of some 20 different electric utility companies that participated in design reviews, and culminated in staged fault tests by several of these utilities."

In Venezuela, the death of two brothers who had come in contact with a downed

feeder led Electricidad de Caracas to seriously investigate the viability of Hi-Z testing device --

prompting the Venezuelan utility's work with GE Power Management to move on to testing the Hi-Z algorithm.

The research in Caracas involved a series of staged fault tests where several lengths of conductors were laid on various surfaces, including wet and dry pavement, sand, rock and others.

"Through testing of the Hi-Z device under a variety of fault conditions, we were able to approach relay settings that would meet the certainty levels we were looking for," comments the Protection Group at Electricidad de Caracas.

#### **A matter of determining probabilities**

As D'Aversa explains, it is the randomness and energy levels of harmonics tracked over a set period of time that will distinguish a fault from a normal occurrence. "These patterns allow us to determine the confidence level that the current seen by the relay really contains arcing. The sensitivity setting for the device will establish the confidence level that the relay will require before issuing a Hi-Z output. Obviously, in an area where there is a load generating many arcs and harmonics, sensitivity settings would need to be somewhat different as opposed to a remote area where there are fewer electrical devices on a feeder."

"Hi-Z testing is not a deterministic approach, where you can set a breaker to trip at a certain fixed reading," says Kazik Kuras, Regional Manager, Western Canada, for GE Power Management, who has been involved in staged fault testing efforts in Canada.

"It's a case of establishing probabilities. There are a host of variable factors that can come into play. For example, there

might be capacitor banks supporting the voltage level of the feeder, but as the banks are switched in and out, they generate ‘arcing’ currents on the line that have to be taken into account by the relay settings.”

Kuras adds that up to 80 per cent of faults are single phase-to-ground faults. “However, because of the different surface properties within geographical areas, there is no way of determining

what percentage of ground faults are high-impedance faults. The incidence of high-impedance faults in a dry area such as Texas will obviously be much higher than in a moist, tropical area such as Brazil. But regardless of the regional breakdowns, when one realizes that the ultimate goal is to save lives and avoid potential disasters from ground or forest fires, Hi-Z testing is an absolutely essential requirement for any utility.”

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**A video of the live test conducted in Caracas, Venezuela – monitoring an arcing current igniting some foliage -- can be viewed at [www.ge.com/edc/pm/dfp200](http://www.ge.com/edc/pm/dfp200).**

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